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# COMMAND, CONTROL AND COMMUNICATIONS ($C^3$) SYSTEMS MODEL AND MEASURES OF EFFECTIVENESS (MOEs)

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SY Harmon
RL Brandenburg


15 October 1980

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(PME 107)

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NAVAL OCEAN SYSTEMS CENTER
SAN DIEGO, CALIFORNIA 92152

NAVAL OCEAN SYSTEMS CENTER, SAN DIEGO, CA 92152

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Technical Director

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The logical structure of a new comprehensive $C^3$ system model which is independent of national origin and tactical situation and which forms the basis for development of a computer simulation for analysis of $C^3$ systems performance is introduced. Three classes of $C^3$ MOEs which when taken together completely describe all the critical elements of $C^3$ system's performance are also introduced. One of these MOE classes (ie, the MU class) includes most of the MOEs which have been proposed and utilized previously. In addition, two other classes are proposed which include a measure of the effects of information consistency (ie, the ALPHA-BETA class) as well as a completely new class of MOEs describing the knowledge differences between the elements of a force and

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between two opposing forces (ie, the DELTA-K class). Each of these classes of MOEs has both local and global interpretations which permit the evaluation of the component parts of a $C^3$ system as well as of the performance of the $C^3$ system as a whole.

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## OBJECTIVE

The objective of this work is to define the basic logical structure of a $C^3$ model which will support the identification of measures of effectiveness of $C^3$ systems and the development of a comprehensive computer simulation of any $C^3$ system.

## CONCLUSIONS

The logical structure of a new comprehensive $C^3$ system model which is independent of national origin and tactical situation and which forms the basis for development of a computer simulation for analysis of $C^3$ systems performance is introduced. Three classes of $C^3$ MOEs which when taken together completely describe all the critical elements of $C^3$ system's performance are also introduced. One of these MOE classes (ie, the MU class) includes most of the MOEs which have been proposed and utilized previously. In addition, two other classes are proposed which include a measure of the effects of information consistency (ie, the ALPHA-BETA class) as well as a completely new class of MOEs describing the knowledge differences between the elements of a force and between two opposing forces (ie, the DELTA-K class). Each of these classes of MOEs has both local and global interpretations which permit the evaluation of the component parts of a $C^3$ system as well as of the performance of the $C^3$ system as a whole.

## RECOMMENDATIONS

The $C^3$ model proposed herein should be enhanced to permit the complete description of a $C^3$ system. These enhancements will support the further definition and description of the DELTA-K class of MOEs. The interactions between the MOE classes should be explored in order to enrich the representation of the intricacies of actual $C^3$ systems. Future research should also include the study of node cluster dynamics and the extended representation of the command node knowledge domains. Work must begin on definition and implementation of the basic node and link structure in a computer simulation using the concepts developed to date. This will include representing internode message transport and content, circuit loading effects, and the effects of circuit outages or node destruction on system performance. An initial set of specific MOEs should be defined and implemented for each of the three classes for use in the on-line analysis of simulation results.

## INTRODUCTION

The rapid growth in the strength and sophistication of the Soviet Navy and its supporting command, control, and communications ($C^3$) system has placed dramatically increased demands on the US Navy and the Navy Command and Control System (NCCS). A dominating factor in the growth of the Soviet threat which appears to have been developed as part of a large integrated weapon system including the Soviet naval $C^3$ system is the antiship cruise missile (ASCM). Countering the ASCM threat will involve not only engaging the missile itself but also understanding and countering the Soviet $C^3$ system which directs the missile targeting process.

Unfortunately, very little is presently understood about the underlying generic properties of $C^3$ systems and the functions which they must perform. Consequently, the formulation of measures of effectiveness (MOEs) for $C^3$ systems has faltered. A demonstrable result of this situation is the proliferation of $C^3$ systems whose effectiveness and utility are unmeasurable. Identification and development of an effective means for countering the Soviet $C^3$ system or, for that matter, development of cost effective improvements to our own $C^3$ system will be exceedingly difficult without a comprehensive set of MOEs. In order to acquire the needed MOEs, it is first necessary to develop a single comprehensive and integrated model of $C^3$ processes. Then, using the premises of this model, it will be necessary to derive a complete set of quantifiable MOEs.

Several models of $C^3$ processes have previously been proposed by other investigators. Lawson[1,2] has proposed an innovative model of $C^3$ processes which capitalizes upon the similarities between the behavior of military forces and

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1. Lawson, JS, A Unified Theory of Command and Control, presented at the First ONR/MIT Workshop on Distributed Communication and Decision Problems Motivated by Naval $C^3$ Systems, Cambridge, MA, 1-18 August 1978
2. Lawson, JS, The State Variables of a Command Control System, presented at the Second ONR/MIT Workshop on Distributed Communication and Decision Problems Motivated by Naval $C^3$ Systems, Monterey, CA, 16-27 July 1979

certain thermodynamic systems. However, this model is still in the early stages of development and, as yet, has not supported the development of $C^3$ system MOEs. Kugel and Owens[3] have developed seven separate models of the various processes which support $C^3$ functionality. In addition to the difficulties inherent in using several concurrent models of the same situation none of these models provide a basis from which to derive MOEs. Rona[4,5] and Goodbody[6] have proposed models of $C^3$ processes as well as measures by which to evaluate their effectiveness. Rona suggests 12 MOEs for $C^3$ systems and Goodbody suggests 10 such measures. However, neither of these models provide MOEs which are directly quantifiable and measurable. Indeed, while MOEs should never be developed without consideration of measurement feasibility, few of those which have been suggested in the past reflect an awareness of the difficulties of measurement and, therefore, have limited utility.

A new model of $C^3$ processes is described in this report. This model is more concise and comprehensive than those which have been proposed previously and is based upon the premise that the functions of a $C^3$ system can be completely described by the behavior of information within that system. This model forms the basis for derivation of MOEs and for subsequent development of a computer simulation of any actual or postulated $C^3$ system. Following a brief introduction to the model, the premises are used to derive and discuss three classes of MOEs, in canonical form, from which all possible MOEs for any given situation can be developed. These MOEs are quantifiable and are related to such physical entities as time, messages, and knowledge.

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3. ESD-TDR-65-183, Models of Command and Control Systems (With Applications To Exercise and Analysis), by P Kugel and MF Owens, Technical Operations Research, Burlington, MA, February 1965

4. Rona, TP, Conceptual Framework for Military $C^3$ Assessment, Boeing Aerospace Corp, Seattle, WA, November 1977

5. Rona, TP, Generalized Countermeasure Concepts in $C^3$, presented at the Second ONR/MIT Workshop on Distributed Communication and Decision Problems Motivated by Naval $C^3$ Systems, Monterey, CA, 16-27 July 1979

6. NELC TD 504, Navy Command Control and Communications System Design Principles and Concepts, by R Goodbody, et al, 15 August 1976

## $C^3$ MODEL

The goal in the development of this model of $C^3$ processes is simplicity. This is not to say that $C^3$ processes are simple. Obviously, they are complex in the aggregate. But, a simple comprehensive model is required in order to examine those processes and render them tractable by application of decomposition and synthesis techniques. The modeling of $C^3$ processes begins with the representation of the primary military situation as shown in figure 1. Here, two adversary forces are interacting with one another and with the surrounding environment. Since the interaction between these two forces is hostile the information exchanged is not friendly and, probably, not intentional. While this illustration serves as a useful starting point for the development of a $C^3$ process model, it is very general and rather fuzzy. It is necessary to introduce another critical premise of this model to aid further decomposition of the $C^3$ process structure. This premise is an analogy between robot systems and processes and $C^3$ systems and processes.

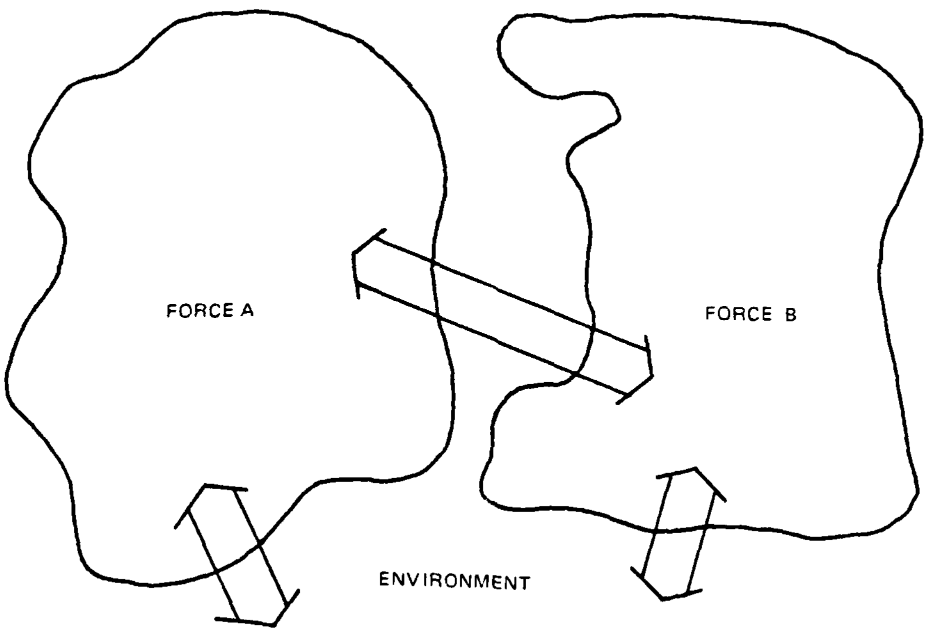


Figure 1. Model of Military $C^3$ Situation.

## Robots and $C^3$ Systems

The robot analogy proceeds as follows. The fundamental components of robots are sensors, effectors, and the processing required to integrate action with perception. Today, most robots have relatively few sensor domains and very restricted behaviors. In the future, robots can be expected to rival many of the more complex biological systems in terms of sensor and effector domains. Like robot systems, $C^3$ systems have sensors, effectors (action units, ie, platforms, weapons and sensor control systems which are distinct from the sensors themselves), and the processing (command and control) necessary to integrate the appropriate actions with the demands of the perceived situation. This analogy is depicted in figure 2. Treating a $C^3$ system as a robot system establishes a unified system perspective which is essential to simplifying the understanding of $C^3$ systems. This analogy may seem less appropriate when one observes that the components of a force are geographically distributed and can consist of many commands, not just one.

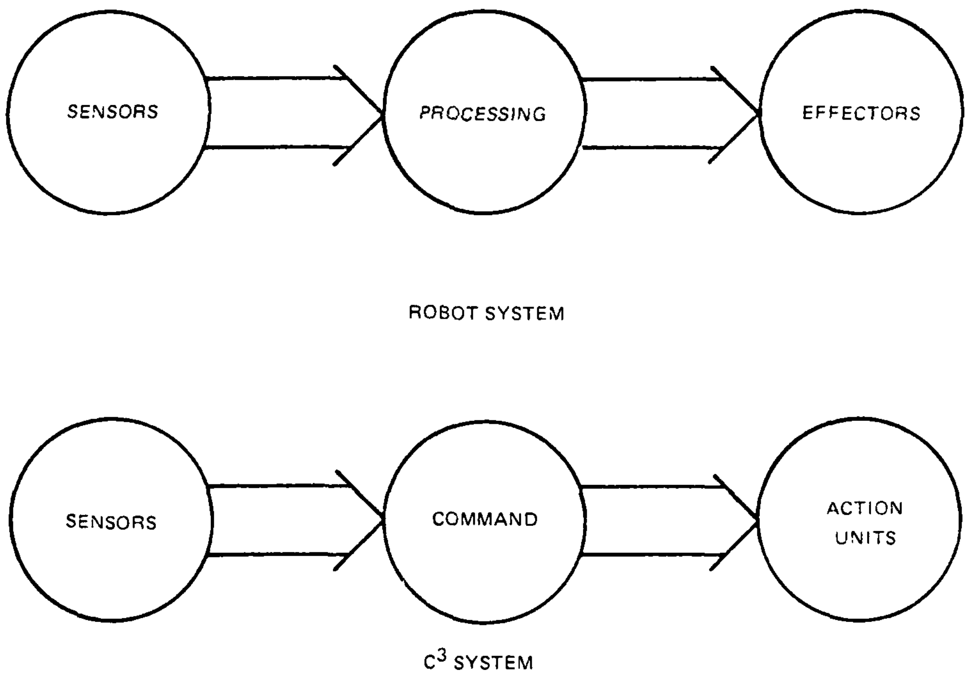


Figure 2. Analogy Between Robot and $C^3$ Systems.

However, this problem may be overcome by taking advantage of the property of robot systems which allows them to be decomposed into subsystems of robots. When multiple robots interact to achieve a common goal there is generally a requirement to exchange information over common communications links. Using the robot analogy, $C^3$ systems may be decomposed by representing the components of the force as individual "robots." Each of these robots has the sensors, action units, and command associated with the force component that it represents. These robots are interconnected by the force communications links.

A natural step in the development of a $C^3$ process model is the mapping of a force structure into a representative network structure. This mapping includes the representation of the various force components in terms of node clusters as shown in figure 3. There are four primary elements in a $C^3$ network:

(1) Communications links
(2) Sensor nodes (S)
(3) Action nodes (A)
(4) Command nodes (C)

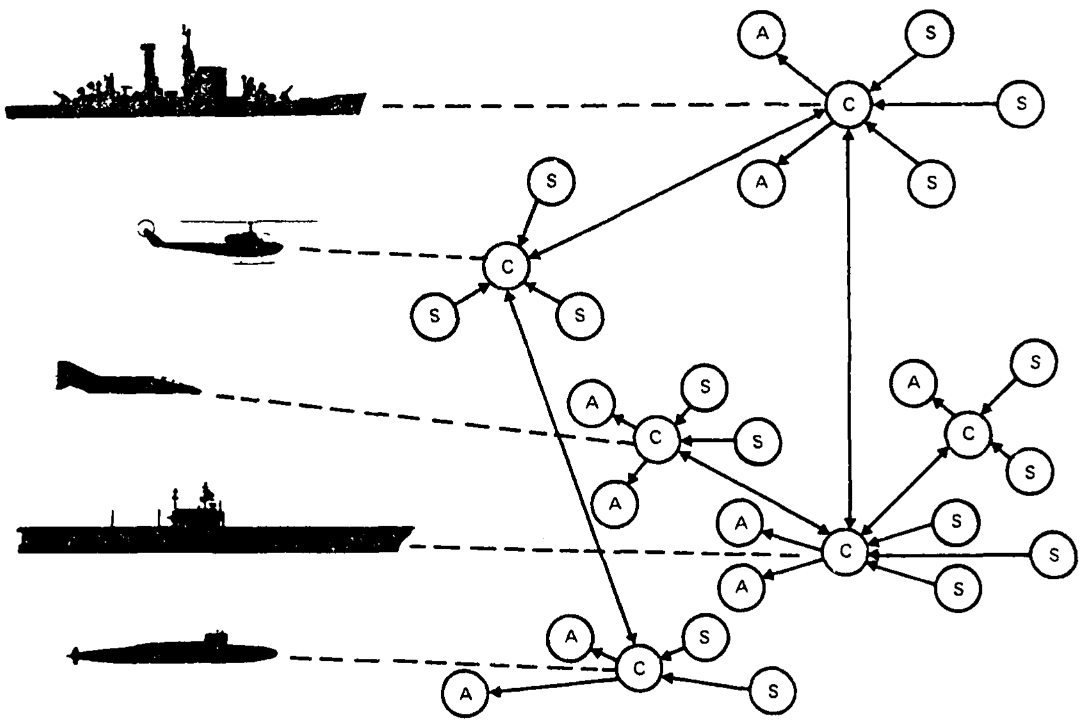


Figure 3. Force to $C^3$ Network Mapping.

Since each node type exerts unique influence upon the information in the $C^3$ system, it is important to understand the various types of information before considering the behavior of the nodes and the links in the network.

## $C^3$ System Information

There are two fundamental types of information in both robot systems and $C^3$ systems:

(1) Knowledge
(2) Messages

Knowledge is stored information which is associated with a particular command and commander. It is typically stored as paper documents, microfiche, photographs, magnetic tape, paper tape, and even human memory. Messages represent information which is not integrally associated with a particular node. They are communicated information and they make transitions between nodes. When messages arrive at the destination node they can become bound to that node by being integrated into the knowledge structure of the node. When this occurs the knowledge structure of the node is modified and, thus, affects the future behavior of that node. The representation of information within a $C^3$ network is portrayed in figure 4. Note that the term "information" as used here is not used in the same sense as described by Shannon.[7]

Figure 4 shows that knowledge structures are associated only with command nodes. Sensor nodes report discrete physical events which occur both external and internal to the force. However, sensor nodes have no knowledge of the meaning or relation of these observations to other events. Action nodes receive tasking messages but, like sensor nodes, they have no continuing knowledge structure. Clearly, there can exist n-ary network subrelationships; for example, a command node wishing to task an associated sensor node would send a message to the associated action node which controls some aspect of the

7. Shannon, CE, The Mathematical Theory of Communication, The University of Illinois Press, Urbana, IL, 1964

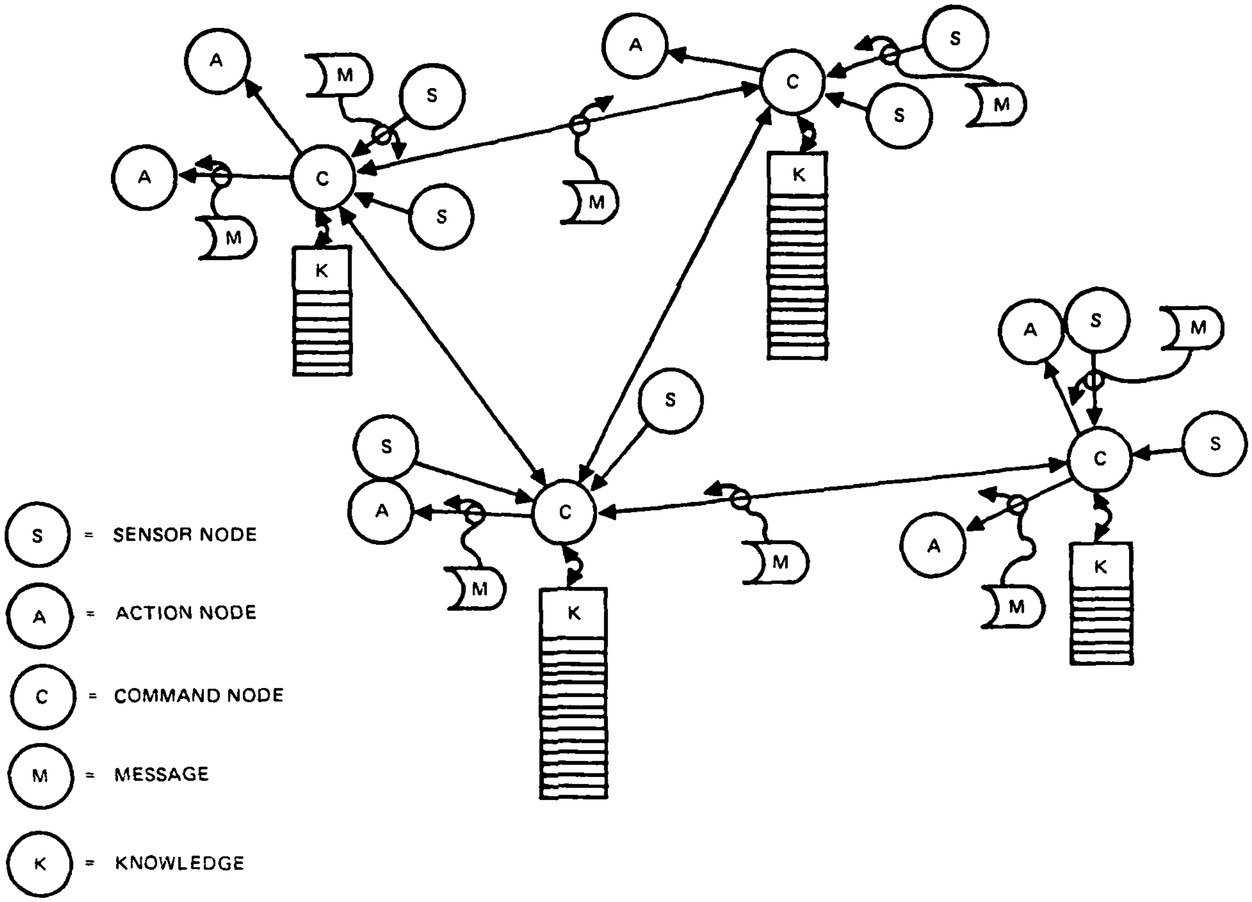


Figure 4. Information Representation in a $C^3$ Network.

sensor's perspective (eg, sensor bearing). Similarly, an action node (such as a weapon) could have an associated sensor node which keeps the governing command node informed of that weapon's status. Examples of this type of node clustering are shown in figure 4. The details of how nodes behave singly and as members of clusters will be examined in further investigations and will be described in subsequent reports.

Information is derived from the environment by the sensors of the system. The sensor nodes then transform that information into messages which are sent to associated commands. These messages describe the present state of the surroundings. No decisions are made at sensor nodes.

The information contained in messages received from sensor nodes is integrated into the associated command nodes' knowledge structures. Decisions on required actions are derived from the state of the command knowledge. These decisions take the form of action orders communicated through communications links to the appropriate action nodes. The functionality of the command nodes is by far the most complicated of any element of the network. Communications between clusters of sensor and action nodes occur only through the associated command nodes. This model is simplified by assuming that messages from sensors are sent only to command nodes and that messages to action nodes originate only at command nodes. However, the details of the complexity of command nodes and how that complexity might be simplified are topics for future reports.

In summary, this model is founded upon (1) an analogy between robot systems and $C^3$ systems, (2) a mapping of the components of a force and a $C^3$ system into a network of nodes and connecting links, and (3) the identification of the two types of information present in $C^3$ systems, knowledge, and messages. These fundamental concepts, while insufficiently developed to support a detailed model of an actual $C^3$ system, permit the derivation of a complete set of MOE classes which can be applied to any $C^3$ system. This capability demonstrates the power of these relatively simple concepts.

## MEASURES OF EFFECTIVENESS

Based upon the assumption that the behavior of information (both as messages and as knowledge) is the most important aspect of $C^3$ systems, three classes of MOEs can be derived from the $C^3$ model as presented herein. The first of these classes is currently recognized as important by evaluators of $C^3$ systems and is applied to most $C^3$ system analyses.[8] This class is the MU class of MOEs or information mobility and is related to the time delays inherent in $C^3$ systems. The second MOE class is generally recognized as critical to all $C^3$ systems; currently, there are no suggestions as how to approach the quantification of this MOE much less its evaluation in real $C^3$ systems. This class is the ALPHA-BETA class of MOEs or information consistency. The final class of MOEs, which has neither been discussed extensively nor suggested as either a property or a criterion of $C^3$ systems, is the DELTA-K class or knowledge differences. This class is believed to be a new class of MOEs which promises to be the most critical of all the classes suggested herein. These three and only these three classes provide the basis from which all specific MOEs can be derived.

### MU Class

Information mobility or MU describes how rapidly information moves between the nodes of a $C^3$ network (figure 5). At sometime T, a message which is destined for node 2 enters node 1 at location 1. Providing that the message is not lost (ie, the information of the message is conserved), at time T + DELTA-T the message will emerge from node 2 after having traversed the physical distance from location 1 to location 2. The interval DELTA-T describes the time required by node 1 to process the message, plus the time required to transmit the message over the communications link between node 1 and node 2, plus the time required by node 2 to process the message before acting upon its

8. Schutzer, D, Command, Control and Communication - Some Design Aspects, presented at the Second ONR/MIT Workshop on Distributed Communication and Decision Problems Motivated by Naval $C^3$ Systems, Monterey, CA, 16-27 July 1979

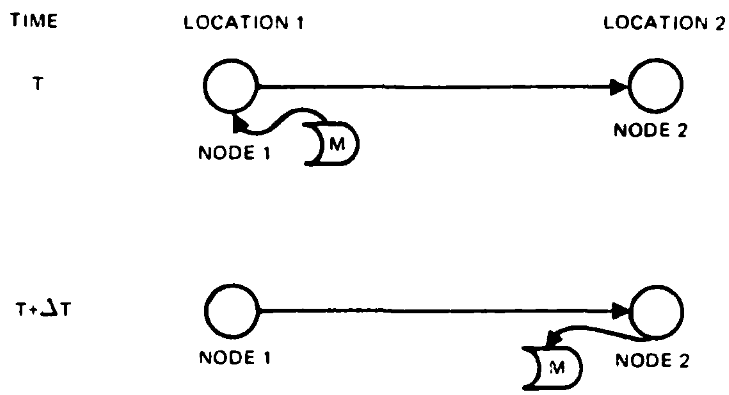


Figure 5. Information Mobility Processes.

information. MU, in the guise of time delay, is undoubtedly the MOE most commonly used today. The relative time delay between two opposing forces has been suggested as a more accurate measure of the effective performance of $C^3$ systems rather than the simple absolute time delays commonly observed at present.[9] However, this is only one class of MOEs and alone they are insufficient to completely describe the performance of $C^3$ systems. This observation is supported by the present inability to fully understand $C^3$ system performance.

## ALPHA-BETA Class

The issues of the consistency or reliability of information within a $C^3$ system may be explored by considering the creation and annihilation of information as a result of $C^2$ processes. Information creation and annihilation refers to the processes which handle messages at sensor and command nodes. When a message is generated by a sensor in response to a sensed event, the information contained by that message is in effect created by the sensor. Likewise, if a message is lost or misrepresented by some element of a $C^3$

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9. Harris, G, A Methodology for Appraising the Combat Effectiveness of the $C^2$ System (NCCS), presented at the Second ONR/MIT Workshop on Distributed Communication and Decision Problems Motivated by Naval $C^3$ Systems, Monterey, CA, 16-27 July 1979

system then the information contained by that message is annihilated. Information creation and annihilation in $C^3$ systems are complicated by the existence of true and false information. Information which is true, is information that faithfully represents the occurrence of some event in the surroundings. False information, on the other hand, merely appears in isolation from other related information to represent some real event. This implies that both information creation and annihilation can have desirable and undesirable consequences. These consequences are directly related to the issues of concern of information consistency.

There are many possible instances of information creation processes within $C^3$ systems as described above. However, all of these fall into one of two categories: (1) information created as a result of an event and (2) information created spontaneously by a node. Figure 6 illustrates the instances of information creation both from event-related processes and spontaneous processes.

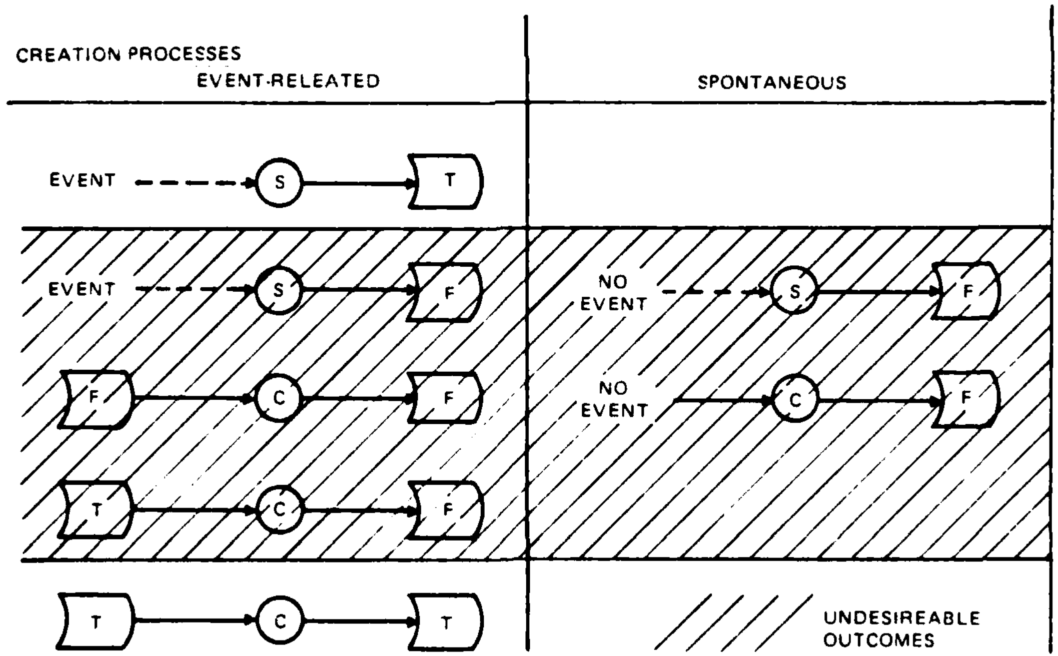


Figure 6. Information Creation Processes.

The occurrence of events in the surroundings should excite information creation at those sensors that can observe those events. Unfortunately, creation of true information from those observations is only one of the two creation possibilities. False information may also be created as a result of a stimulating event. However, if a sensor creates information spontaneously then that information is always considered to be false information. Clearly, the creation of false information and false alarms whether event-related or spontaneous is an undesirable situation.

The behavior of command nodes with regard to information creation is similar to the behavior of sensor nodes. However, incoming messages to command nodes are equivalent to events to sensor nodes. Unlike actual events, messages may be either true or false. A command node may also create either true or false information upon receiving a message. However, if a false message is received then any message which is created as a result of that message can only be false in the sense that some unintended result may occur. Further, as with sensors, if a true message is received then there is the possibility that either a true or a false message may be created. Message creation which is not related to some actual event always leads to the creation of false information. Obviously, the only desirable form of information creation in a $C^3$ system is the creation of true information as a result of actual events.

As with information creation processes, there are two types of information annihilation, noncontaminating and contaminating. Noncontaminating information annihilation only destroys information. Contaminating information annihilation is accompanied by the creation of a false information by-product. Figure 7 illustrates the instances of both types of information annihilation.

Figure 7 also illustrates that communications links can contribute to the information annihilation processes which are occurring within a $C^3$ system. This is the only nonconservative type of information process which may occur at a communications link as assumed in this model. A sensor node may annihilate the information produced by an event. Unlike a communications link, a sensor node may also create contaminating information. Similarly, command

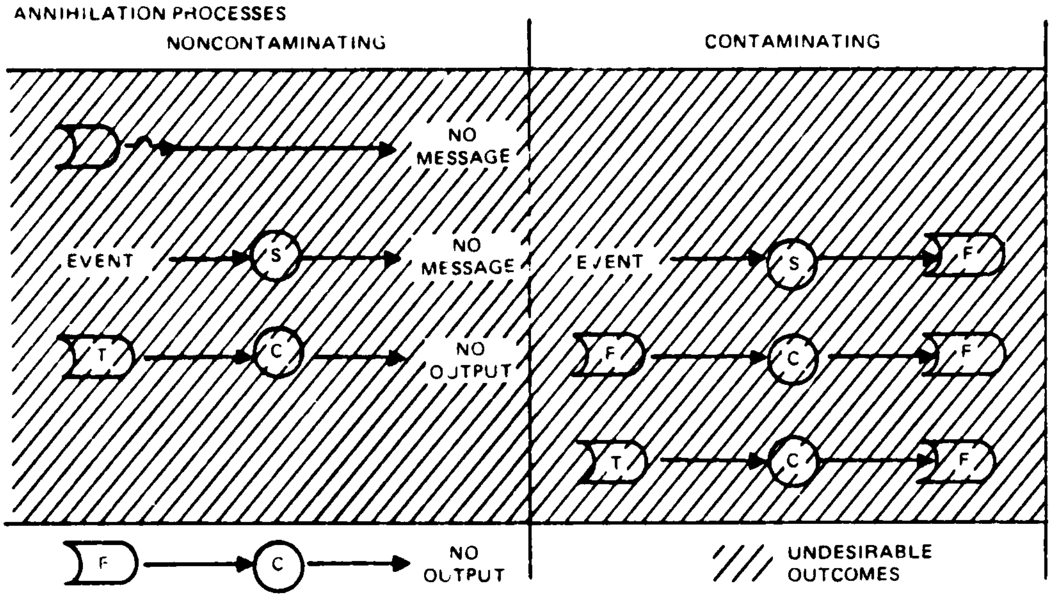


Figure 7. Information Annihilation Processes.

nodes may annihilate information either with or without accompanying contamination. However, command nodes may annihilate either true or false information with resulting false contamination. Note that if information is annihilated and some information by-product results, then that information is always false. In this case command nodes are assumed to communicate with their associated knowledge bases through messages. Fortunately, command nodes may also annihilate false information without producing contamination. This is the only instance where information annihilation processes have a positive effect upon the overall performance of the $C^3$ system.

Clearly, the information creation and annihilation processes of a $C^3$ system can dramatically affect the validity of the knowledge associated with the command nodes. The validity or consistency of a force's information is diminished by two processes: (1) rejecting true information and (2) accepting false information. These two processes correspond to the familiar ALPHA and BETA classes of errors in testing statistical hypotheses, respectively.[10] This is the rationale behind naming this class of MOEs the ALPHA-BETA class.

At this point, these processes can nearly completely describe the conditions which affect the consistency of the information contained by a force. The ALPHA-BETA class of MOEs complements the MU MOE class, thus, considerably enriching the description of $C^3$ system performance.

## DELTA-K Class

The final class of $C^3$ system MOEs is the class for which no MOEs have previously been proposed. This class of MOEs also complements the other two classes and completes the set of canonical MOEs required for the description of $C^3$ system performance. This class consists of DELTA-K MOEs or knowledge differences and describes the variations of knowledge which exist at the different command nodes at any one time. DELTA-K MOEs are the most difficult to define and quantify because of their inextricable association with knowledge. Figure 8 depicts the concepts which are important to knowledge differences.

The term knowledge difference (DELTA-K) refers to the difference in knowledge contained by two different command nodes. If these nodes are associated with the same force then it is desirable that the DELTA-K between them be small. This condition implies that each command node has a similar picture of the current situation as well as of the expections and goals for the future. Sizeable DELTA-Ks can arise between communicating nodes as a result of information annihilation and creation processes, as well as information hiding. Information hiding occurs when one node does not communicate some of its knowledge to another node. In this case the information is not annihilated but, rather, just not circulated. In some cases large DELTA-Ks between the nodes of the same force may be desirable (ie, as is the case with sensitive information). However, in general, the smaller the DELTA-K existing between two

10. Hoel, PG, Introduction to Mathematical Statistics, 4th ed, John Wiley & Sons, Inc, New York, NY, 1971

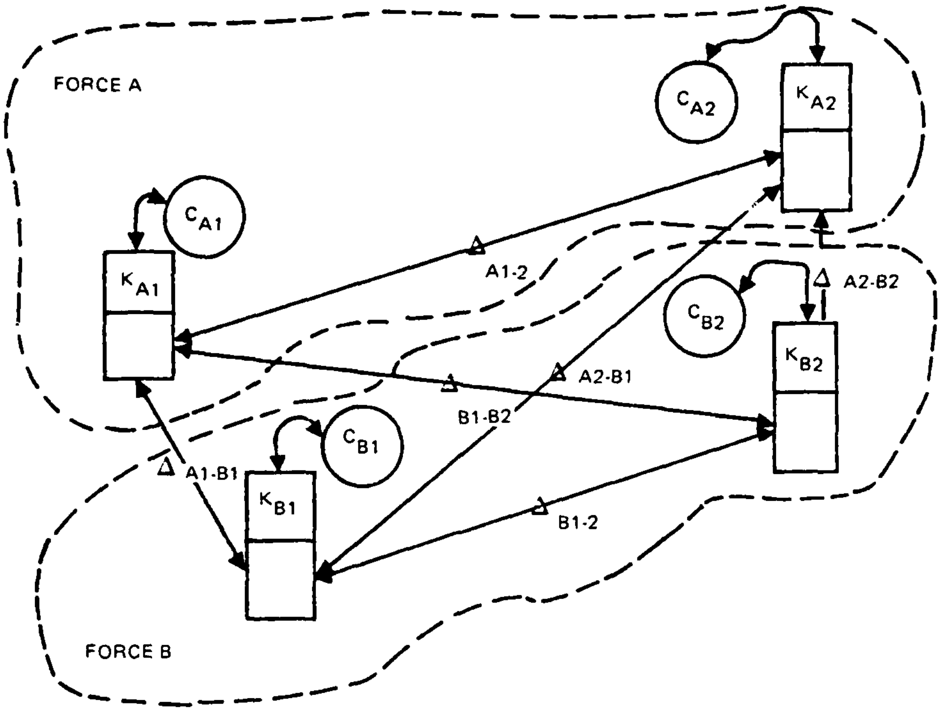


Figure 8. Intraforce and Interforce Knowledge Differences.

nodes of the same force the better. It is also important that the DELTA-Ks between these nodes and ground truth be as small as possible. However, the deviation of a force's knowledge from ground truth results from adverse annihilation and creation processes and is, therefore, encompassed by the ALPHA-BETA class of MOEs.

When considering the knowledge differences between the nodes of different and opposing forces, large DELTA-Ks are highly desirable in all cases. The characterization of the DELTA-K MOEs requires detailed study of the knowledge element sets which reside in command nodes at all levels of a $C^3$ hierarchy and of the sensitivities of the knowledge element subsets with respect to command node missions, available resources, policy constraints, and the operating environment. Research is currently being performed to resolve these issues and the results will be published in subsequent reports.

Each of the classes of MOEs can be described in terms of either local or global perspectives. An illustration of these two perspectives is provided in figure 9. A local perspective describes a MOE of either a single atomic node or an elementary group of two atomic nodes (for those internode MOEs). In figure 9, the single node MOEs are represented by the parameter p whereas the group MOEs are represented by the parameters q. The parameter p can represent the intranode information mobility, the intranode information creation processes, and the intranode information annihilation processes. The parameter q can represent the internode information mobility, the internode annihilation processes, and the knowledge differences.

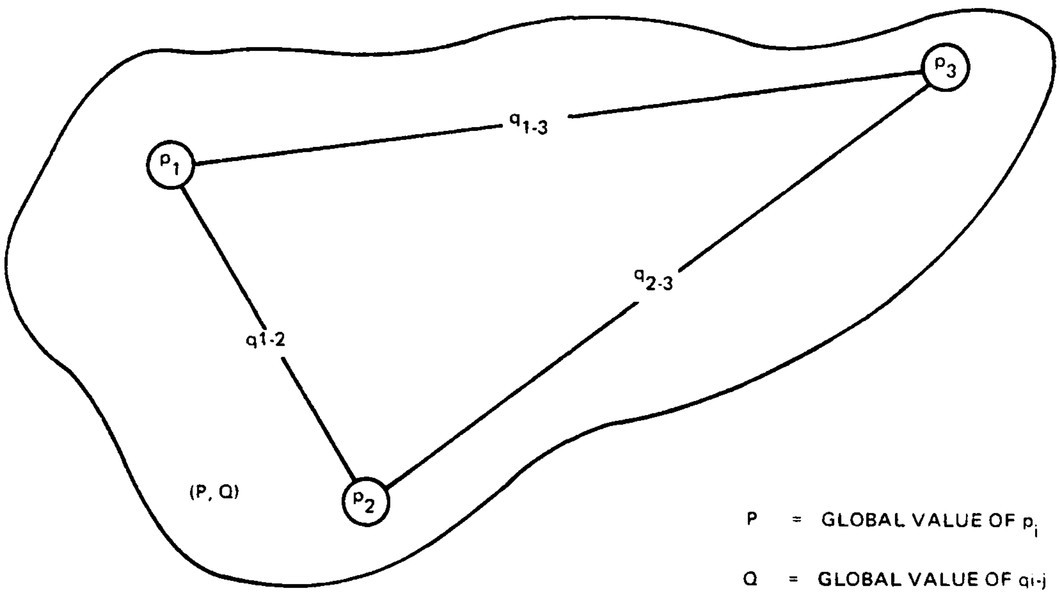


Figure 9. Local and Global Measures of Effectiveness.

The global perspective describes those MOEs that can be applied to a force as a whole. Global MOEs are represented by p and q. These MOEs are functions of the local values within the force and serve to depict the performance of a total $C^3$ system rather than the individual components of that system. Each of the three classes of MOEs is represented by both local and global values. The local and global values will most likely differ in all but the most simple $C^3$ systems.

There is interaction between the foregoing classes of MOEs. For instance, the filtering of false information through annihilation is certainly dependent upon the rate that information propagates through the $C^3$ system (as determined by information mobility (MU)) relative to the stimulating event's occurrence rate. Likewise, true and false information creation and annihilation (ALPHA-BETA) affects the departure of a force's knowledge from ground truth and, as a result, from an opposing force's probable knowledge (DELTA-K) (assuming that the two interacting forces do not suffer from exactly the same $C^3$ system affliction). There is similar interaction between the MU and DELTA-K classes. These class interactions are the subject of current research efforts.

## CONCLUSIONS

The logical structure of a comprehensive $C^3$ system model which is independent of national origin and tactical situation and which forms the basis for development of a computer simulation for analysis of $C^3$ systems performance has been introduced herein. The premise of this model has been used to derive three classes of $C^3$ MOEs which when taken together COMPLETELY describe the critical elements of $C^3$ systems performance. These MOE classes include most of the MOEs which have been proposed and utilized by others. Measures of the effects of information consistency as well as a completely new class of MOEs describing the knowledge differences between the elements of a force and between two opposing forces are proposed. Each of these classes of MOEs has both local and global interpretations which permit the evaluation of the component parts of a $C^3$ system as well as of the performance of the $C^3$ system as a whole. These three MOE classes and their components are summarized in table 1.

| MOE Class | Internode MOEs | Intranode MOEs |
|---|---|---|
| [illegible] class | Information mobility | Information mobility |
| [illegible] class | Information annihilation | True information annihilation<br>False information annihilation<br>True information creation<br>False information creation |
| [illegible]k class | Intraforce knowledge differences<br>Interforce knowledge differences | |

Table 1. Summary of $C^3$ System MOEs.

The MOEs proposed herein do not focus on specific situation issues (eg, sensor error, target position error) but instead describe the properties which form the essence of $C^3$ system performance. A significant shortcoming of MOEs proposed in the past is that they do not provide direct insight into the sources of problems in the $C^3$ systems themselves (as distinct from the supporting sensor and weapon systems). As a result, these past MOEs have not adequately supported failure mode analysis. The approach to the understanding of $C^3$ system performance, proposed here, permits a clear distinction between $C^3$ systems themselves and other systems that provide information to them. This property allows the direct identification of $C^3$ system performance deficiencies with the components of the system that are responsible for those deficiencies. This capability is a significant improvement over that offered by past MOEs of $C^3$ systems.

Clearly, MOEs should not be developed irrespective of measurement techniques. However, very few of the MOEs which have been suggested in the past reflect an awareness of the difficulties of measurement. Unmeasurable MOEs are nearly useless. The measurement (of the MOEs) which has been proposed in this report appears at first to fall into the category of unmeasurable MOEs. However, further consideration will reveal that these MOEs are measurable because they are related to physical entities (eg, messages, knowledge, time) which are routinely measured by operations analysts, psychologists, and teachers in numerous other applications.

The classical approach to $C^3$ developments in the past has been to construct a proposed new system and test it in Fleet exercises. This approach has historically been less than satisfactory because of the time and cost involved and because of the difficulties in obtaining complete and accurate performance data for post-analysis. Now, however, there is an alternative.

The development of the Warfare Environment Simulator (WES) at the Naval Ocean Systems Center (NOSC) has provided a comprehensive real time man-interactive simulation environment in which it is possible to conduct any evolution that can be carried out by real forces at sea. The span of possible simulations ranges from one-on-one platform engagements to multiple battle groups engaging enemy forces in a multidimensional warfare environment. The

WES environment is ideal for the implementation of the $C^3$ model and its accompanying MOEs. The cost of running WES is infinitesimal compared to the costs of actual at-sea operations. The system records and provides complete and accurate data for postanalysis. Exercises can be repeated and replayed in complete detail, thus enhancing analysis. Finally, but by no means last, WES operates in a secure environment which provides the necessary protection for $C^3$ countermeasures being developed and tested.

Dramatic reductions in development costs and similarly important economies in the employment of scarce Fleet assets for research and development purposes, can be achieved by using WES to develop and test countermeasures, tactics, and new system concepts to the maximum extent before trying them in actual Fleet exercises.

## RECOMMENDATIONS

While this report has introduced a new comprehensive model of $C^3$ systems together with the MOEs which can be derived from this model, a number of unresolved issues and questions still remain. The model should be enhanced to permit the complete description of a $C^3$ system. The interactions between the MOE classes should be explored in order to enrich the representation of the intricacies of actual $C^3$ systems. Future research should also include the study of node cluster dynamics. Work should continue on the representation of the command node knowledge domains. Work should begin on definition and implementation of the basic node and link structure in a computer simulation using the concepts developed this far. This work should include representing inter-node message transport and content, circuit loading effects, and the effects of circuit outages or node destruction on system performance. This initial increment of the simulation will use simple fixed logic decision structures to represent a commander's knowledge base. An initial set of specific MOEs should be defined and implemented for each of the three classes for use in the on-line analysis of the simulation results.

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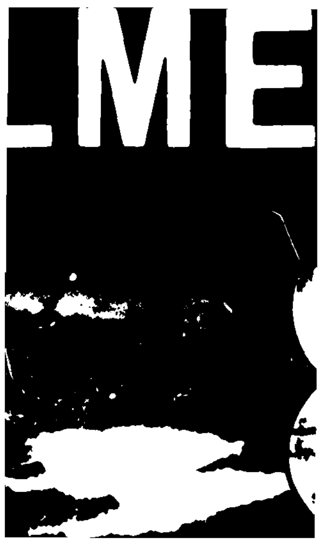
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